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THE ROLE OF MATHEMATICS IN THE PALESTINIAN ECONOMY: ESTIMATING THE SPEED OF THE SWALLOWING OF PALESTINIAN LANDS BY THE ISRAELI SETTLEMENTS

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Abstract

The purpose of this paper is to demonstrate the importance of mathematics in the Palestinian economy by deriving a dynamic model for the speed –the rate of change – of the expansion for the Israeli settlements and thus the “swallowing” rate of Palestinian lands. Partial Differential Equations were used to derive a theoretical model for the “swallowing” rate of Palestinian lands by Israeli settlements, which in turn result in tremendous negative effects on both the agricultural and industrial sector of the Palestinian economy. The developed dynamic model explains the process of which the Israeli settlements expands and the variables affecting the “swallowing” rate. The data was plotted and a mathematical equation was fitted for the growth rate of the settlements. This will give the policymakers an approximation of how fast the settlements are expanding and may aid them in their strategic planning of Palestinian development.

Keywords: Swallowing of Palestinian lands, Israeli Settlements, Gompertz Model, Palestinian Economy, Partial Differential Equation

1. Introduction

Since one of the most threatening challenges facing the existence of the Palestinian people is the expansion of the Israeli settlements, this is due to the continuous increase in the number of Israeli settlements living in the West Bank. The purpose of this paper is to develop a dynamic model that estimates the speed – the rate of change – of the expansion of Israeli settlements. This paper demonstrates the importance of mathematics in the Palestinian economy through the derivation of a dynamic model that is causing the "swallowing" of Palestinian lands. This is a crucial issue as the spread of the Israeli settlements are an indication to the end of the Palestinian dream in having an independent Palestinian state. This paper will aid in creating a theoretical framework in understanding the process by which the settlements are expanding. More mathematical literature should be geared towards this issue.

The Israeli settlements are a major part of the Israeli occupation, where the restrictions that are imposed by the Israeli authorities – in order to secure the settlements – are used as a tool to have political, geographical, and economical control over the Palestinian resources. By doing so, the Israeli occupation is transformed from a military occupation to colonization and thus removing the Palestinians from their homes. From the first day, the occupation had the intension of controlling the natural resources of the nation. This is achieved by spreading its settlements in East Jerusalem, the Jordan Valley, and north of the Dead Sea as part of a plan in order to control the water resources, mining resources, and tourist sites. The Israeli strategy had been to increase the number of settlements and expand those existing. The Israeli authorities had also worked on creating a network of roads that connect settlements together and with the other side of the Green Line. In addition, the Israeli implemented a strategy of building industrial sites in the West Bank that serve the settlements, encouraging tourism in the settlements, and building institutions in the settlements that serve both the settlers and Israeli citizens outside of the West Bank. All this has been done on the expense of Palestinian lands.

The various economic indicators demonstrate the burden that the settlements have on the Israeli economy. In addition to all that, the settlements contribute to the change of demographics for the advantage of the Israelis in the West Bank (Atrash, 2014). The settlements affect negatively the following Palestinian economic sectors:

1. The agricultural sector is affected directly from the existence of the settlements, where the amount of land that can be used by Palestinians for agriculture is continuously decreasing. In addition, the total control of the water resources by the Israelis in the Palestinian territories due to the existence of the settlements affects the agricultural sector negatively.
2. The manufacturing sector is limited by the expansion of the settlements, where the settlements are occupying lands that can be used to build industrial zones. In addition,

settlements are built in locations that are strategic for manufacturing sites. For example, settlements are built along the Green Line. If the manufacturing site is built there, it will be closer to both Israeli and Palestinian markets. It will also be closer to seaports.

3. The increase in the number of settlers in the West Bank is colonizing more land that is affecting the expansion of the Palestinian cities. Thus, strategic planners have to constantly re-organize the patterns of expansion of Palestinian cities. In addition, it is driving the price of land in the Palestinian territories to rise. Thus making it more expensive for Palestinians to own or rent property.

(Atrash, 2014) Table 1 shows the number of settlers living in the Israeli settlements in the West Bank including Jerusalem by region.

Table 1: Number of Settlers in the West Bank Settlements by Year and Region, 1986-2016

Year	West Bank (excluding Jerusalem)	Jerusalem	West Bank
1986	60766		
1987	67483		
1988	73403	117550	190953
1989	79842	123061	202885
1990	88888	132460	221348
1991	100729	137331	238060
1992	111673	140872	252545
1993	122320	146436	268756
1994	133572	152219	285791
1995	140235	156724	296959
1996	153974	159684	313658
1997	167124	158929	326053
1998	179087	162842	341929
1999	190750	170400	361150
2000	205113	173986	379099
2001	215062	175987	391049
2002	226712	178437	405149
2003	240313	181425	421738
2004	252737	184944	437681
2005	265049	187573	452622
2006	279479	190534	470013
2007	294133	193485	487618
2008	298961	197071	496032
2009	314101	196803	510904
2010	328774	200545	529319
2011	343350	205088	548438
2012	359571	205746	565317
2013	373995	209912	583907
2014	387949	214362	602311
2015	400988	218297	619285
2016	414127	222325	636452

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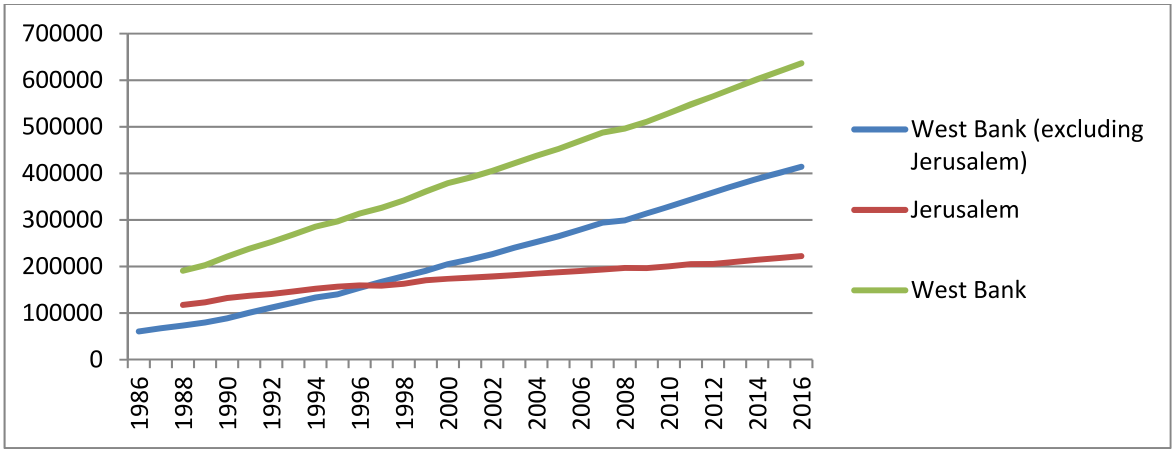
Source: Palestinian Central Bureau of Statistics

Graph 1: Increase in the Number of Settlers over Time



The graph and table above show a continuous increase in the number of Israeli settlers over time. In 1988, the total number of settlers was 190,953 were 117,550 settled in Jerusalem and 73,403 settled in the rest of the West Bank. In 1994, the Palestinian Authority took control of Jericho; the total number of settlers was 285,791 with 152,219 in Jerusalem and 133,572 in the rest of the West Bank. Thus, the number of settlers increased by approximately 29 percent in Jerusalem and approximately 82 percent in the rest of the West Bank since 1988. Meanwhile, in 2016 the total number of settlers reached 636,452 with 222,325 in Jerusalem and 414,127 in the rest of the West Bank. Thus, the number of settlers increased by approximately 43 percent in Jerusalem and approximately 210 percent in the rest of the West Bank since the year 1994. Clearly, time is not a constraint to the Israeli government; on the contrary, it is to their benefit. This shows the true intensions of the Israeli government towards giving up the West Bank despite of the signing of the Oslo Agreement with the Palestinians. The above data asserts that the Israeli government invested sufficiently in time to change the demographics on the ground to their advantage in the West Bank and create a new reality. Therefore, the settlements are a major obstacle to the two state solutions.

The monotonically increasing function shown in the graph clearly reflects the continuous increase in the number of Israeli settlers. Nonetheless, in this paper we are interested in the time and space dimension. The above table does not show the amount of land occupied by the Israeli settlers. However, the continuous increase in the number of Israeli settlers in the West Bank causes an increase in the demand for housing and associated services –such as schools, medical centers, shopping centers, universities, etc. - in the settlements. This continuous increase results in an upward pressure on the price of land in the settlements and adds extra pressures to expand the borders of the settlement. This will have further implications in our analysis in creating the theoretical framework for estimating the amount of "swallowing" of Palestinian lands.

Let us take a closer look at some spatial facts concerning the settlements. The total area of the West Bank is 5664.5 km^2 including East Jerusalem, where the settlements occupy 2.7% of the total area of the West Bank. In addition, the settlements have an "area of jurisdiction" that is larger compared to the settlement built up area within the fence. The area of jurisdiction of settlements exceeds 9.3% of the area of the West Bank. Moreover, the settlements are connected with a well-developed road network that takes 2.3% of area to connect settlements together and connect them to their center of life in Israeli (Samara, 2019).

The table in Annex I shows the number of settlers living in each of the settlements, the initial area occupied by the settlement when it was first established, and the area of each settlement in 2016.

Table 2 shows only the settlements not including the illegal outposts. The table indicates that the largest settlement in terms of number of settlers is Modi'ih Ilit with 66,847 and the smallest is Niran with 91. Nonetheless, these two settlements are not the largest and smallest in terms of area. The largest settlement in terms of area is Bet Arye with 7814 m^2 and the smallest is Rotem with 55 m^2. From looking at the table above, we also notice that most of the settlements were established in the eighties.

2. Literature Review

In the 1970s, a new generation of mathematical urban theories manifested. These theories formed the new urban economics. This approach was successful in explaining certain economic and geographical phenomena in urban systems. In addition, it was also able to explain the behavior of households and firms in urban systems. Nonetheless, the problem was that most of the models in this approach required perfect competition. So, an assumption was made that both households and firms had perfect information about housing and land markets (Mills & Mackinnon, 1973).

In reality, urban development processes are dominated by imperfect information and disequilibrium. Thus, relaxing the assumption of perfect competition leads us to urban development models of geographical diffusion. These models describe dynamic urban development pattern formations by PDEs in which temporal and spatial economic development processes can be dealt with simultaneously. These models are aimed at trying to explain how urban patterns might be far away from the equilibrium determined by the new urban economics (Zhang, 1988).

Zhang (1988) developed a dynamic model for urbanization in the regional system containing the Central Business District, the urban, and the rural areas. The paper had described "eating up" of rural areas by the expanding the organization. Partial differential equations were used to represent

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the spatial and temporal land prices of the urban and rural areas. It's also asserted the movement of the boundary of the urban areas. Three differential equations were used to demonstrate the movement of the boundary, and the deviation from the equilibrium due to the inflationary forces. It was concluded by construction of analytic solution for the fixed rural land price.

Kaashoek and Paelinck (1994) potentialized the spatial variables to generalize the partial differential equation in order to be used in spatial economics. This process was carried out for one dimensional wave equation. Linear, exponential, and tanner potentials were investigated. The result of the analysis had led to the utilization of the exponential equation in producing meaningful analytical solutions for spatial economic patterns. This paper has also discussed the problems of stability and strangeness of the dynamical solutions.

Kaashoek and Paelinck (2001) used potentialized wave and diffusion equations to emphasis the relationship between the resulting process and potentializing parameters. Empirical relevance to spatial economics was mentioned and discussed.

Redding and Rossi –Hansberg (2017) described what was achieved as a result of the utilization of quantitative models in spatial economic in this decade.

Marquez, Lasarte, and Lufin (2019) proposed a measurement for the procedure for the role of geographical position in economic inequality. In addition, they aimed to determine an approach for the decomposition of global inequality into both within and between countries components in order to assess which of these components is a result of neighborhood factors. This was applied to European countries. Based on the inequality analysis certain policies were recommended.

Vallone (2019) used geo-computation in spatial economic analysis. He constructed and applied a new set of algorithms and functions in the R programming language to deal with spatial economic data.

Portilla, Maza, and Villaverde (2019) examined the effects of inward FDI on economic growth –focusing on the headquarters effect- across the Spanish regions over the time period of 1996 to 2013. The paper had concluded that FDI does not always register where it is effectively made, but instead in the region in which the firm's headquarters is located. This is achieved by estimating a panel spatial spillovers results: FDI does foster economic growth, only when the headquarters effect is properly addressing the question do spatial spillovers arise.

The above literature had asserted how spatial economics had developed over time. Now let us consider how mathematics was used in the Palestinian economy.

Paul de Boer and Marco Messaglia (2006) utilized mathematics and statistics to estimate the income elasticities and their use in a CGE model for Palestine. They used the Linear Expenditure Systems (LES) to estimate the consumption block for the computable general equilibrium model (CGE). To represent reality – where non-straight Engel curves, inferior commodities, elastic demand, and gross substitution exist – the use of the Indirect Addilog System (IAS) was suggested. Thus, the income elasticities of the IAS were estimated from the 1998 Palestinian Expenditure and Consumption Survey (PECS). Calculating the income elasticities using the IAS model helped in trying to explain the consumption behavior.

Samarah (2016) studied the relationship between Gross Disposable Income (GDI) and consumption, and the consumption function for Palestine was estimated. Three econometric models were constructed to estimate the consumption function and calculus was used to derive the Marginal Propensity to Consume (MPC) in both the short and long run.

The key determinants of poverty status a household since the implementation of the economic reform program in Palestine were also identified using mathematical and statistical techniques. Through the utilization of the Logistic Regression Model it was found that the chance of a household to fall into poverty increases due to the unemployed adults, the large number of children below 18 years old, and the large dependency ratio (Elnamourty & Safi, 2012).

Mathematics was also able to analyze the impact of the size of domestic working labor force, Real Gross Domestic Capital Formation, real domestic exports and imports of goods and services, as well as political instability on the Real Gross Domestic Product (RGDP) in Palestine. The Cobb-Douglas function was used to formulize the functional relationship between the explanatory variables and the RGDP. The study had indicated the urgent need for increasing the level of investment into the Palestinian economy (Abu-Eideh, 2014).

Samarah (2018) had proved that there is a functional relationship between governance and economic growth in Palestine using real analysis. Thus, economic growth is a function of governance.

This paper will use partial differential equations to derive a dynamic model to better understand the rate of change in which the Israeli settlements are expanding in the West Bank. Thus, this paper will add a more regress and theoretical approach to the already limited existing literature.

3. Spatial Economics

In recent years, Partial Differential Equations (PDEs) had played an important role in economics. An example is the large literature on the design of optimal dynamic contracts and policies (Farhi & Werning, 2013). Labor economics, was another area in which PDEs were used in modeling the labor markets (Alvarez & Shimer, 2011) and reviewed by (Lentz & Mortensen, 2010).

A system of nonlinear PDEs was also used to model heterogeneous agents sharing a common mathematical structure over time. Thus, PDEs were able to present a continuous time formulation of the simplest model to study the effect of various policies and institutions on the inequality of income and wealth distributions (Achdou, Lasry, Lions, & Moll, 2014).

To understand the growth rate of the Israeli settlements, we will discuss how spatial economics based on a single space dimension x and time t can model reality. PDEs had long represented space-time dimensions. Thus, we will use PDEs to model the expansion patterns of the Israeli settlements. Let us look at some examples of how PDEs can be used in spatial economics to describe the pattern of evolution of cities over space-time dimension.

Considering only one space variable x and time t, a PDE for some function f(x,t) is a relation of the form:

$$g(x,t;f;\ f_x,f_t\ ;f_{xx},f_{xt},f_{tt};\ \ldots) = 0$$

In the above equation g –in general- is a given function of both the independent variables x and t; of the unknown function f; and a finite number of its partial derivatives.

Nonetheless, in order to apply PDE to human spatial behavior we need two fundamental adoptions. The first is that the interaction at a distance should be taken into consideration explicitly. Thus, Potentialzed Partial Differential Equations (PPDE) is considered. Thus, applying to the classical PDE the idea of "potential function". The second adaption is the interpretations of PPDE in the presence of a bifurcation parameters relating to the openness of the spaces studied (Kaashoek & Paelinck, 2001, p. 464). A parameter is a numerical or other measurable factor forming on of a set that defines a system or sets the conditions of its operations. A Bifurcation parameter is most commonly used in the mathematical study of dynamic systems. A bifurcation occurs when a small smooth change made to the parameter values (the bifurcation parameters) of a system causes a sudden quantitative or topological change in its behavior.

Let us now consider the classical wave equation

$$\ddot{f}(\mathrm{x,t}) = \alpha^2 f''(x,t)$$

This equation is an expression of local interaction. However, in spatial economics locality is rather the exception. Thus, in order to express the spatial interaction the wave equation should be generalized as follows:

$$\ddot{f}(\mathrm{x,t}) = \alpha^2 \int_{-l}^{+l} w(x,\xi) f''(\xi,t)\, d\boldsymbol{\xi} \qquad (\mathbf{1})$$

Where $w(x,\xi)$ is called a "spatial discount function", it represents the potential of a convolution with some variable over the line [-l,+l]. Thus, equation 1 is potentialized equation. Using the separation variable technique, we can rewrite the above equation as:

$$u(x)v(t) = \alpha^2 v(t) \int_{-l}^{+l} w(x,\xi) u''(\xi)\, d\xi$$

(Kaashoek & Paelinck, 1994, p. 585). Implying that

$$f(x,t) \triangleq u(x)v(t)$$

Let us now take a linear spatial discount function over the closed interval [-1, 1],

$$w(x,\xi) = \mathbf{1} + \tfrac{\mathbf{1}}{\mathbf{2}}(\boldsymbol{\xi} - \boldsymbol{x}),\ \boldsymbol{\xi} < x..$$

$$= \mathbf{1} + \tfrac{\mathbf{1}}{\mathbf{2}}(\boldsymbol{x} - \boldsymbol{\xi}),\ \boldsymbol{\xi} \geq x.$$

The potential function is

$$p(x) = \int_{-1}^{x} \boldsymbol{u}''(\boldsymbol{\xi})[\mathbf{1} + \frac{\mathbf{1}}{\mathbf{2}}(\boldsymbol{\xi} - \boldsymbol{x})]\, d\boldsymbol{\xi} + \int_{x}^{+1} \boldsymbol{u}''(\boldsymbol{\xi})[\mathbf{1} + \frac{\mathbf{1}}{\mathbf{2}}(\boldsymbol{x} - \boldsymbol{\xi})\, d\boldsymbol{\xi}$$

Integrating the potential with a factor of 1 will give us the following

$$\boldsymbol{p_1(x) = [u'(1) - u'(-1)]}$$

Integrating with a factor of x gives

$$\boldsymbol{p_2(x) = -xu'(x) + \frac{1}{2}[u'(-1) - u'(1)]x}$$

Finally, in

$$\boldsymbol{\frac{1}{2}(\int_{-1}^{x} u''(\xi)\xi d\xi - \int_{x}^{+1} u''(\xi)\xi d\xi)}$$

The indefinite integral is

$$\boldsymbol{u'(\xi)\xi - u(\xi)}$$

By integration by parts and collecting the terms we get

$$p(x) = c + ax - u(x),$$

With

$$c \triangleq \frac{1}{2}[u'(1) - u'(-1) + u(1) + u(-1)\}$$

$$a \triangleq \frac{1}{2}[u'(1) - u'(-1)]$$

The linear potential implies a straight line passing through the origin and rotating with time (Kaashoek & Paelinck, 1994, p. 587).

Let us now take an exponential spatial discount function

$$w(x, \boldsymbol{\xi}) = \boldsymbol{\frac{1}{\gamma} exp(-\frac{|x - \xi|}{\gamma})}$$

In the above equation, $\boldsymbol{\gamma}$ is a scaling variable and $\boldsymbol{\gamma} > 0$. Then the potential function is

$$p(x) = \boldsymbol{\frac{1}{\gamma}\left\{\int_{-1}^{x} u''(\xi) exp\left[\frac{x-\xi}{\gamma}\right] d\xi + \int_{x}^{+1} u''(\xi) exp\left[\frac{x-\xi}{\gamma}\right] d\xi \right\}}$$

Refer to Kaashoek and Paelinck (1994) for the solution. "The resulting behavior is not unlike representing the occupational density of a city and its evolution over time" (Kaashoek & Paelinck, 1994, p. 588).

4. The Theoretical Framework for the Expansion of Settlements

In this section, we will use spatial economics to describe the speed of the growth of the Israeli settlements inside the West Bank and Jerusalem over time. We will develop a theoretical model that will describe the process of the border movement of the settlements. Our theoretical model will identify the factors that affect the movement of the borders. Thus, the theoretical model will explain the process of how the settlements expand and provide the theoretical framework for the evolution of the Israeli settlements.

A vital aspect of spatial economics in general is that in principle all relevant variables are spatially interrelated. The choice of space-and-time specifications is manifested naturally in a theoretical analysis. PDE contains these specifications, they allow the demonstrations of movement simultaneously over space –whatever is the dimension- and time. When solving such equations, the ideal solution is a function that contains the values of the considered variables in the analysis for every point in space and time.

We will start our analysis by developing a dynamic model for a representative Israeli settlement. We will then generalize the model to include all the settlements.

The total land for the region is constant –the total area of the West Bank including Jerusalem. The center of the system is in the center of the Israeli settlement and the system is symmetric. The Israeli settlement is located in the center and the Palestinian areas are surrounding the settlement. The Israeli settlement is causing the "swallowing of the Palestinian lands". The dynamics of the system are spatial and temporal movements of the following variables:

I(x,t) is the land prices in the Israeli settlement' areas at (x,t)
P(x,t) is the land prices at the Palestinian areas at (x,t)
B(t) is the distance from the center of the Israeli settlement to the boundaries that separate the Palestinians from the Israeli areas.

Where P, B, and I belong to the set of real number.[1]

The equilibrium land prices for both Israel and Palestine are determined using the supply and demand for land in the Israeli and Palestinian markets respectively over time and space dimensions. In other words, equilibrium land prices are determined by the forces of supply and demand for the two distinct markets. However, the actual land prices are not only dependent on the classical economic theory of supply and demand. Actual prices are also dependent on political factors such as the majority in the Knesset, the tradeoff between political turmoil and regional stability adopted by policy makers in the region, and political pressures from the outside. Thus, it is important for us to consider the difference between the actual land prices and the equilibrium land prices for both Israeli and Palestine.

Here I and P represent the deviations of the actual land prices from the long-run equilibrium land prices. Let us express the long-run equilibrium determined on the basis of the new urban economics as (i*(x), p*(x)) which is independent of time, and the actual regional pattern by (i(x,t), p(x,t)), then we will have the following

$$I(x,t) = i(x,t) - i^*(x)$$
$$P(x,t) = p(x,t) - p^*(x)$$

Thus, when we talk about land prices, we mean the deviations of the actual land prices from the equilibrium.

Assume that a positive excess supply is associated by positive prices and vice versa. In addition, there are other exogenous forces that will cause the deviation in the Palestinian prices of land from their equilibrium. In this study we are interested in the speed of the movement of the boundaries. Since we assume that the Israeli settlements should not exist so over the long-run the Israeli settlements would not exist and the entire West Bank including Jerusalem should be free from settlements. However, as mentioned before we are only interested and focused on the situation at the boundaries.

We assume that the speed of the movement of the boundary –dB(t)/dt- is negatively proportional to the gradient of the Palestinian land prices at the boundary. That is when the Palestinian land prices decrease the Israeli settlement boundaries will be tempted to expand at a fast rate. Meanwhile, if the prices are high the boundary will move at a slow rate. Usually, in the Palestinian areas the high prices of the Palestinian lands are associated with a high density of the Palestinians and as a result the boundaries of the settlement will not be tempted to move forward. In other words, the boundary will move at a very slow pace. The movement of the Israeli settlement boundary is positively proportional to the Israeli land prices in the settlement. A high land price at the settlement is usually associated with a high demand to live in that settlement and as a result, the boundary is pressured to expand.

Consider the location B(t)-δx in the Israeli settlements where δx is positive and sufficiently small. The gradient of the Israeli land prices near the boundary is represented as follows

$$\{I(B(t)-0,t)-I(B(t)-\delta x,t)/\delta x$$

The above equation represents the Israeli settlement price per mile between the boundary and its neighborhood. The value is usually negative, so we consider the absolute value. The larger the absolute value the more easily the boundary is moved.

Let us now consider the Palestinian land prices near the boundary represented by B(t)+δy, where δy is positive and sufficiently small. The gradient of the Palestinian land prices near the boundary is

$$\{P(B(t)+\delta y),t)-P(B(t)+0,t)\}/\delta y \ ,$$

The speed of the movement of the boundary is given by

$$\frac{dB(t)}{dt}= h\{I(B(t)-\delta x,t)\}/\delta x-kP\{B(t)+\delta y,t)-P(B(t)+0,t)\}/\delta y$$

In the above equation, h and k are non-negative parameters. We will now allow for δx and δy to go to 0, then we can rewrite the above equation as:

$$\frac{dB(t)}{dt}=\{h\frac{\partial I}{\partial x}-k\frac{\partial P}{\partial x}\} \quad x=B(t)$$

This equation describes the movement of the boundary. This is known as the Stefan condition (Zhang, 1988, p. 335). The above equation represents the expansion of the representative Israeli settlement and thus we obtain the “swallowing” rate of the Palestinian lands by the representative Israeli settlement. Looking at the above equation, it is clear that the difference in land prices in the Israeli settlements and the Palestinian territories affects the expansion rate of the border. Given that the land prices in the Israeli settlement are higher than the land prices in the Palestinian territories, the greater is the difference the faster is the expansion rate of the border. Thus, the land prices along the two sides of Israeli settlement border are crucial to the rate of expansion.

Since the difference in prices is not the only factor that causes the expansion of the settlement, we will add the variable u(x,t) to represent the additional rate of expansion due to the political decision of the Israeli government that is not captured by land prices. The Israeli government’s strategy is

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geopolitical, where its sole propose is to create a major in balanced favoring the Israeli population in the West Bank. Hence, we will have the following equation

$$\frac{dB(t)}{dt} = \{h\frac{\partial I}{\partial x} - k\frac{\partial P}{\partial x}\} + u(x, t) \quad x=B(t),$$

where u belong to the set of real numbers.

Here u is an exogenous variable, i.e. it is determined by factors outside the model. Nonetheless, there is not only one settlement in the occupied Palestinian territories. Therefore, we need to expand our model to include the n number of Israeli settlements and thus estimate the aggregate expansion rate for all the Israeli settlements as given below:

$$\sum_{i=1}^{n} \frac{dB_i(t)}{dt}$$ Where n is a positive integer greater than 0

The above equation describes the rate of expansion of the borders for all the Israeli settlements in the West Bank including Jerusalem. Clearly, the equation will result in a finite number and the rate of expansion is limited to the actual total area of the West Bank that is under the control of the Israeli government. Only in these areas can the settlements grow. The areas controlled by the Palestinian government –known as area A- are protected against the expansion of the Israeli settlements.

Notably, the rate of expansion for each settlement is different depending on the difference between the Israeli and Palestinian land prices along the borders of the settlement. Unlike normal economic transactions, the leakage of Palestinian land to the Israeli government's ownership is a shady deal. The Palestinians are usually subjected to identity theft Israeli institutions and the transaction is carried out on their behalf. Nonetheless, if this does not work other ways are adapted by the Israeli government in order to carry out the transaction. Finally, if all fails the Israeli authorities uses force and confiscate the land. In all cases, Israelis are willing to compensate the Palestinians if they agree to sell land. The price they offer is usually dependent on the Palestinian price of land. The higher the Palestinian price the higher is the Israeli price and the harder it is for the Israelis to give an offer. At the end of the day, the Israelis best interest is to show that they bought the land rather than taking it by force.

5. Data and Methodology

The data for the initial area and the area in 2016 for each of the settlement was taken from the Wafa organization website. Meanwhile, the establishment date and number of settlers inhabiting the settlement was taken from the B'tselem website.

With the aim of trying to estimate a functional equation for the expansion rate of the Israeli settlements, we will calculate the cumulative sum for the initial areas of the settlements. The cumulative sums are then plotted against time (t). We will then fit a model to estimate the "swallowing" rate of the Palestinian lands.

6. Results

The Excel program was used to analyze the data. Where the results of the analysis are given below.

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Table 3: Total Growth. Years Passed, Growth Rate and Cumulative Sum for each of the Israeli Settlements

Data settlement (1)	Date of Establishment	Initial Area (m^2)	Area in 2016 (m^2)	Number of Settlers in 2016	Total Growth	Year passed	growth rate	Cumulative sum
Kfar Etzion	1967	258	567	1099	1.197674419	49	1.61991889	258
Mehola	1968	241	288	517	0.195020747	48	0.37186376	499
Qalya	1968	271	771	386	1.84501845	48	2.2021674	770
Argaman	1968	109	353	131	2.23853211	48	2.4783807	879
Rosh Tzurim	1969	247	463	934	0.874493927	47	1.34586723	1126
Alon Shvut	1970	492	463	3180	-0.058943089	46	-0.1319817	1618
Mevo Horon	1970	603	524	2566	-0.131011609	46	-0.3048074	2221
Ma’ale Efrayim	1970	359	489	1209	0.362116992	46	0.67408812	2580
Yitav	1970	117	322	321	1.752136752	46	2.2252176	2697
Gilgal	1970	181	727	178	3.016574586	46	3.06881924	2878
Massu’a	1970	162	692	162	3.271604938	46	3.20684493	3040
Mizpe Shalem	1971	72	108	174	0.5	45	0.9051051	3112
Hamra	1971	123	261	124	1.12195122	45	1.68591165	3235
Kiryat Arba	1972	466	787	7272	0.688841202	44	1.19812666	3701
Har Gilo	1972	224	507	1570	1.263392857	44	1.87385157	3925
Beka’ot	1972	115	344	187	1.991304348	44	2.52151462	4040
Gittit	1973			430	#DIV/0!	43	#DIV/0!	4040
Mechora	1973	103	171	142	0.660194175	43	1.18589422	4143
Ma’ale Adumim	1975	3291	7010	37670	1.130051656	41	1.86137059	7434
Ofra	1975			3605	#DIV/0!	41	#DIV/0!	7434
Elazar	1975	265	349	2568	0.316981132	41	0.67382615	7699
Petza’el	1975	319	897	257	1.811912226	41	2.55368316	8018
Netiv Hagedud	1976	234	1425	190	5.08974359	40	4.62006251	8252
Ro’i	1976	106	164	165	0.547169811	40	1.09704219	8358
Beit El	1977	688	557	6115	-0.190406977	39	-0.540135	9046
Kedumim	1977			4323	#DIV/0!	39	#DIV/0!	9046
Elkana	1977	867	1757	3898	1.026528258	39	1.82758711	9913
Tekoa	1977	527	844	3633	0.601518027	39	1.21488965	10440
Kochav Hashachar	1977	301	1033	1985	2.431893688	39	3.2123429	10741
Neve Halamish	1977	297	2510	1328	7.451178451	39	5.62509426	11038
Bet Horon	1977	235	199	1240	-0.153191489	39	-0.4254531	11273
Shvei Shomron	1977	276	391	897	0.416666667	39	0.89709407	11549

Sal'it	1977	443	691	818	0.559819413	39	1.1464451	11992
Rimmonim	1977			625	#DIV/0!	39	#DIV/0!	11992
Migdal Oz	1977	95	464	605	3.884210526	39	4.1505084	12087
Rehan	1977	86	298	224	2.465116279	39	3.23784211	12173
Almog	1977	107	397	239	2.710280374	39	3.41896153	12280
Niran	1977	107	397	91	2.710280374	39	3.41896153	12387
Ari'el	1978	2378	4729	19220	0.988645921	38	1.82555253	14765
Karnei Shomron	1978	341	631	7102	0.850439883	38	1.63272078	15106
Mitzpe Yeriho	1978	331	747	2319	1.256797583	38	2.16507004	15437
Kfar Tapuah	1978	181	396	1071	1.187845304	38	2.08167924	15618
Mevo Dotan	1978	96	768	386	7	38	5.62470912	15714
Tomer	1978	218	366	262	0.678899083	38	1.37286012	15932
Kfar Adumim	1979	412	693	4271	0.682038835	37	1.41534588	16344
Shilo	1979	387	3247	3727	7.390180879	37	5.91727345	16731
Elon Moreh	1979	381	1047	1861	1.748031496	37	2.76978584	17112
Shademot Mehola	1979	164	363	608	1.213414634	37	2.17061816	17276
Efrat	1980	992	1792	8658	0.806451613	36	1.65624528	18268
Givon Hahadasha	1980			1135	#DIV/0!	36	#DIV/0!	18268
Ma'ale Shomeron	1980			1037	#DIV/0!	36	#DIV/0!	18268
Vered Yeriho	1980			252	#DIV/0!	36	#DIV/0!	18268
Hemdat	1980	75	202	230	1.693333333	36	2.79038742	18343
Beit Ha'arava	1980	75	163	183	1.173333333	36	2.17969937	18418
Yafit	1980	173	297	139	0.716763006	36	1.5125487	18591
Bet Arye	1981	837	7814	4842	8.33572282	35	6.59050329	19428
Psagot	1981			1847	#DIV/0!	35	#DIV/0!	19428
Yaqir	1981	3016	574	1901	-0.809681698	35	-4.6295723	22444
Barkan	1981	411	563	1798	0.369829684	35	0.90315812	22855
Nili	1981	321	1296	1552	3.037383178	35	4.06798411	23176
Ma'ale Mikhmas	1981	221	1507	1323	5.819004525	35	5.63810437	23397
Hinnanit	1981	163	698	1164	3.282208589	35	4.24318015	23560
Ateret	1981	160	3393	875	20.20625	35	9.11864588	23720
Shaqed	1981	229	463	864	1.021834061	35	2.03180884	23949
Einav	1981	183	466	749	1.546448087	35	2.70654924	24132
Mattityahu	1981	149	755	772	4.067114094	35	4.74565564	24281
Ma'on	1981	167	443	539	1.652694611	35	2.82657022	24448
Carmel	1981	182	347	605	0.906593407	35	1.86086829	24630
Ma'ale Amos	1981	89	310	390	2.483146067	35	3.62985855	24719
Neve Daniel	1982	268	457	2278	0.705223881	34	1.58207976	24987
Nokdim	1982	231	336	2052	0.454545455	34	1.10813438	25218

Alei Zahav	1982	339	608	1643	0.793510324	34	1.73300639	25557
Almon	1982	194	689	1329	2.551546392	34	3.79794365	25751
Eshkolot	1982	92	139	515	0.510869565	34	1.22117667	25843
Pnei Hever	1982	98	522	548	4.326530612	34	5.04273297	25941
Telem	1982	95	451	362	3.747368421	34	4.6877039	26036
Hermesh	1982	96	445	223	3.635416667	34	4.61425013	26132
Naama	1982	119	280	116	1.352941176	34	2.54860038	26251
Giv’at Ze’ev	1983	1257	2741	16865	1.180588703	33	2.39053467	27508
Sha’arei Tikva	1983			5811	#DIV/0!	33	#DIV/0!	27508
Immanuel	1983	301	740	3309	1.458471761	33	2.76337051	27809
Har Bracha	1983	238	350	2339	0.470588235	33	1.17552986	28047
Yitzhar	1983	200	1248	1468	5.24	33	5.70523662	28247
Dolev	1983	280	1186	1331	3.235714286	33	4.47148729	28527
Susiya	1983	268	460	1115	0.71641791	33	1.65056316	28795
Otniel	1983	301	740	976	1.458471761	33	2.76337051	29096
Kiryat Netafim	1983	141	339	910	1.404255319	33	2.69395176	29237
Ma’ale Levona	1983	161	503	826	2.124223602	33	3.51235401	29398
Tene	1983	185	390	768	1.108108108	33	2.28570332	29583
Asefar	1983	86	201	688	1.337209302	33	2.60597575	29669
Mezadot Yehuda	1983	208	429	466	1.0625	33	2.21793182	29877
Migdalim	1983	66	136	305	1.060606061	33	2.21508619	29943
Maskiyyot	1983	45	413	253	8.177777778	33	6.94829487	29988
Rotem	1983	44	55	196	0.25	33	0.67848392	30032
Avenat	1983	43	89	193	1.069767442	33	2.22882764	30075
Adam(Geva Binyamin)	1984	457	1324	5278	1.897155361	32	3.38002153	30532
Eli	1984	591	2167	4233	2.666666667	32	4.14381488	31123
Pedu’el	1984			1682	#DIV/0!	32	#DIV/0!	31123
Itamar	1984	182	677	1151	2.71978022	32	4.19063023	31305
Carmei Tzur	1984	135	397	1047	1.940740741	32	3.428273	31440
Nahaliel	1984	90	1585	639	16.61111111	32	9.37821614	31530
Beit Hagai	1984	142	869	573	5.11971831	32	5.82428851	31672
Adora	1984	182	372	421	1.043956044	32	2.25916355	31854
Beitar Illit	1985	2208	3632	51636	0.644927536	31	1.61842899	34062
Oranit	1985			8652	#DIV/0!	31	#DIV/0!	34062
Kochav Ya’akov	1985	564	2311	7394	3.09751773	31	4.65469993	34626
Hasmoneam	1985	752	501	2826	-0.333776596	31	-1.3015531	35378
Etz Efrayim	1985	233	344	2022	0.47639485	31	1.26471525	35611
Qedar	1985	241	365	1555	0.514522822	31	1.34803882	35852
Shim’a	1985	113	172	592	0.522123894	31	1.36440699	35965

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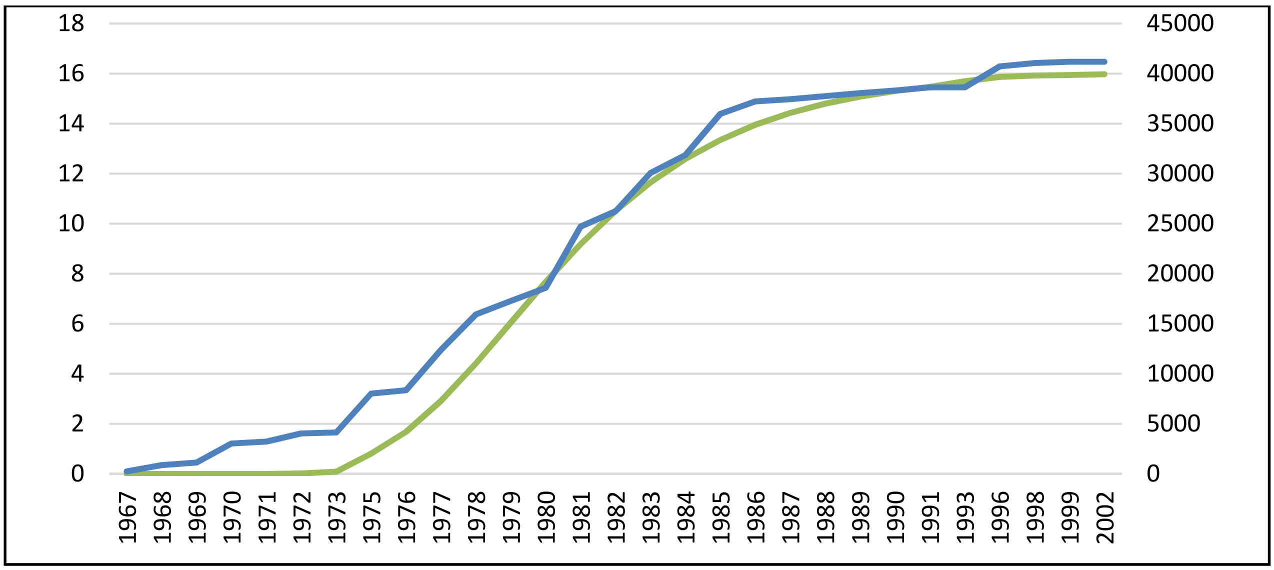
Har Adar	1986	1257	2741	3980	1.180588703	30	2.63270891	37222
Nofim	1987	215	632	690	1.939534884	29	3.7880945	37437
Na'ale	1988	314	1105	1661	2.51910828	28	4.59609024	37751
Talmon	1989			3879	#DIV/0!	27	#DIV/0!	37751
Zufin(Zufim)	1989			2087	#DIV/0!	27	#DIV/0!	37751
Bat Ayin	1989	291	417	1307	0.432989691	27	1.34137213	38042
Avne Hefetz	1990	269	789	1759	1.933085502	26	4.22550974	38311
Revava	1991	240	605	2181	1.520833333	25	3.76759835	38551
Rechelim	1991	67	217	668	2.23880597	25	4.81305926	38618
Alfei Menashe	1993			7780	#DIV/0!	23	#DIV/0!	38618
Modi'in Ilit	1996	2103	4549	66847	1.163100333	20	3.93308853	40721
Kfar Haoranim(Menora)	1998	337	1329	2678	2.943620178	18	7.92083136	41058
Bruchin	1999			818	#DIV/0!	17	#DIV/0!	41058
Sansana	1999	74	188	377	1.540540541	17	5.63776011	41132
Negohot	1999	53	227	289	3.283018868	17	8.93357685	41185
Gilad Farm	2002				#DIV/0!	14	#DIV/0!	41185

Table 4: Cumulative Sum for the Settlements and the Gompertz Model Coefficients

	Cumulative sum			**a**	**b**	**c**
				16	**28**	**0.28**
1967	258	0	1.11E-11			
1968	879	1	1.03E-08			
1969	1126	2	1.81E-06			
1970	3040	3	9E-05			
1971	3235	4	0.001724	**Gompertz model**		
1972	4040	5	0.016049	f(t)=a*(exp(-b*exp(-ct)))		
1973	4143	6	0.08665			
1975	8018	8	0.812004			
1976	8358	9	1.681556			
1977	12387	10	2.915108			
1978	15932	11	4.418187			
1979	17276	12	6.049656			
1980	18591	13	7.671584			
1981	24719	14	9.1801			
1982	26251	15	10.51405			
1983	30075	16	11.64938			
1984	31854	17	12.5881			
1985	35965	18	13.34743			

1986	37222	19	13.95156
1987	37437	20	14.42624
1988	37751	21	14.79567
1989	38042	22	15.08115
1990	38311	23	15.30056
1991	38618	24	15.4685
1993	38618	26	15.6942
1996	40721	29	15.86726
1998	41058	31	15.92404
1999	41185	32	15.94256
2002	41185	35	15.97518

Graph 2: Gompertz Model Function



7. Discussion

Looking at the above results we notice that the growth rate for each settlement vary from -0.81 to 9.38. However, the "Swallowing" rate of the Palestinian lands by the expansion of the Israeli settlements follows the Gompertz function. This is a time series mathematical model that uses a log exponential approximation to describe the growth rate. This rate follows an "S" shape where it is slowest at the beginning and at the end of a given time period.

Looking at the graph in table 4, we notice that there was a slow growth rate in the initial areas occupied by the Israeli settlements from the year 1967 to 1973. In 1967, the Israeli forces had succeeded in occupying the West Bank including East Jerusalem. Immediately after the occupation, the Israeli government quickly began "swallowing" East Jerusalem

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by building settlements. Nonetheless, the rest of the West Bank was not invested in. From 1973 to 1984, the Israeli government moved forward with its plans to "swallow" the rest of the West Bank. This is reflected in our graph by the increase in the growth rate where the slope –rate of change- of the graoh is increasing at an increasing rate. Finally, from the year 1984 to 2002, the growth rate in the number of settlements had started to increase at a decreasing rate. Thus, the Israeli government had continued with its "swallowing" by the building of new settlements but at a much slower pace.

Did the story end here? Unfortunately, not; we now move to our theoretical dynamic model to explain the rate of expansion of each of the existing settlements shown in table 3 under total growth and growth rate. In table 3, we calculated both the total growth and the growth rate for each settlement. However, the lack of data on the prices of land along, the borders of the settlements makes it hard to predict the expansion rate for each settlement.

8. Conclusion

This paper developed a dynamic theoretical model to explain the process by which the existing Israeli settlements are expanding and thus developing an equation to explain the "swallowing" rate of the Palestinian lands. It described a pattern in which the Israeli settlements are far away from their equilibrium – where the West Bank including Jerusalem should have zero settlements. The paper also derived an empirical mathematical time series model that can somewhat estimate the rate of growth of Israeli settlements, which will in turn provide policy makers with a better prediction of the "swallowing" of Palestinian lands.

The theoretical dynamic model outlined by this paper described the expansion of Israeli settlements. The resulting model had asserted that the rate of expansion of the settlements is dependent on the difference in land prices between the Israeli settlements and Palestinian territories and the benchmark set by the Israeli government.

So, are the Palestinians fully aware of the threats from the settlements? The answer is "yes", however the Israeli government had succeeded in creating Palestinian dependency on the Israeli economy (Samarah and Rahman, 2017). This is turn would deter the efforts of Palestinians from slowing down the 'swallowing' of their lands.

What can the Palestinians do to slow down the "swallowing"? One way to prevent the expansion of the settlements by the Palestinian government is to constantly inflate Palestinian land prices along the borders of the settlements. The increase in prices minimizes the price difference between Palestinian and Israeli land. This can be done by providing both financial and logistical support for Palestinians who either live or own land along the borders. In addition, it will relieve Palestinians of the potential Israeli pressure inserted to sell their lands; and finally, it will limit the indirect ways that Israelis use to trick Palestinians into selling their land.

Over the long run as the Palestinian population grows, the demand curve for Palestinian land shifts to the right – given the constant supply of land, which is represented by a vertical line – the equilibrium land price, will increase. Thus, it is important for the Palestinian government to provide all the necessary aid in order to strengthen the steadfastness or Palestinians on their lands.

The ambition of this paper is to open the way for more empirical studies to be conducted based on our theoretical framework and the empirical model. In addition, understanding the patterns of the increase in Israeli settlers and the pace of the settlement expansion will aid policymakers in attempting to limit their growth. Furthermore, policymakers can include the rate of expansion of settlements in their strategic plans and better plan Palestinian urban and rural development. Finally, with such predictions, policymakers can also try to minimize the negative effects of settlements as much as possible.

Annex I

Table 2: The Name of the Settlement, the Date of Establishment, the Initial Area Occupied by the Settlement when Established, and the Area Occupied in 2016.

	Name of Settlement	Date of Establishment	Initial Area (m^2)	Area in 2016 (m^2)	Number of Settlers in 2016
1	Modi'in Ilit	1996	2103	4549	66847
2	Beitar Illit	1985	2208	3632	51636
3	Ma'ale Adumim	1975	3291	7010	37670
4	Ari'el	1978	2378	4729	19220
5	Giv'at Ze'ev	1983	1257	2741	16865
6	Oranit	1985			8652
7	Efrat	1980	992	1792	8658
8	Alfei Menashe	1993			7780
9	Kochav Ya'akov	1985	564	2311	7394
10	Kiryat Arba	1972	466	787	7272
11	Karnei Shomron	1978	341	631	7102
12	Beit El	1977	688	557	6115
13	Sha'arei Tikva	1983			5811
14	Adam (Geva Binyamin)	1984	457	1324	5278
15	Bet Arye	1981	837	7814	4842
16	Kedumim	1977			4323
17	Kfar Adumim	1979	412	693	4271
18	Eli	1984	591	2167	4233
19	Elkana	1977	867	1757	3898
20	Har Adar	1986	1257	2741	3980
21	Talmon	1989			3879
22	Tekoa	1977	527	844	3633
23	Shilo	1979	387	3247	3727
24	Immanuel	1983	301	740	3309
25	Alon Shvut	1970	492	463	3180
26	Ofra	1975			3605

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27	Hasmoneam	1985	752	501	2826
28	Kfar Haoranim(Menora)	1998	337	1329	2678
29	Elazar	1975	265	349	2568
30	Mevo Horon	1970	603	524	2566
31	Mitzpe Yeriho	1978	331	747	2319
32	Neve Daniel	1982	268	457	2278
33	Har Bracha	1983	238	350	2339
34	Zufin (Zufim)	1989			2087
35	Revava	1991	240	605	2181
36	Kochav Hashachar	1977	301	1033	1985
37	Nokdim	1982	231	336	2052
38	Psagot	1981			1847
39	Yaqir	1981	3016	574	1901
40	Etz Efrayim	1985	233	344	2022
41	Elon Moreh	1979	381	1047	1861
42	Barkan	1981	411	563	1798
43	Avne Hefetz	1990	269	789	1759
44	Pedu'el	1984			1682
45	Na'ale	1988	314	1105	1661
46	Har Gilo	1972	224	507	1570
47	Qedar	1985	241	365	1555
48	Nili	1981	321	1296	1552
49	Yitzhar	1983	200	1248	1468
50	Ma'ale Mikhmas	1981	221	1507	1323
51	Itamar	1984	182	677	1151
52	Dolev	1983	280	1186	1331
53	Alei Zahav	1982	339	608	1643
54	Almon	1982	194	689	1329
55	Neve Halamish	1977	297	2510	1328
56	Bet Horon	1977	235	199	1240
57	Bat Ayin	1989	291	417	1307
58	Ma'ale Efrayim	1970	359	489	1209
59	Givon Hahadasha	1980			1135
60	Hinnanit	1981	163	698	1164
61	Kfar Etzion	1967	258	567	1099
62	Susiya	1983	268	460	1115
63	Carmei Tzur	1984	135	397	1047
64	Ma'ale Shomeron	1980			1037
65	Kfar Tapuah	1978	181	396	1071
66	Rosh Tzurim	1969	247	463	934
67	Otniel	1983	301	740	976
68	Ateret	1981	160	3393	875
69	Shvei Shomron	1977	276	391	897
70	Kiryat Netafim	1983	141	339	910
71	Shaqed	1981	229	463	864
72	Ma'ale Levona	1983	161	503	826
73	Tene	1983	185	390	768
74	Bruchin	1999			818

75	Einav	1981	183	466	749
76	Mattityahu	1981	149	755	772
77	Sal'it	1977	443	691	818
78	Nahaliel	1984	90	1585	639
79	Nofim	1987	215	632	690
80	Rimmonim	1977			625
81	Beit Hagai	1984	142	869	573
82	Asefar	1983	86	201	688
83	Rechelim	1991	67	217	668
84	Shademot Mehola	1979	164	363	608
85	Shim'a	1985	113	172	592
86	Ma'on	1981	167	443	539
87	Eshkolot	1982	92	139	515
88	Mehola	1968	241	288	517
89	Mezadot Yehuda	1983	208	429	466
90	Migdal Oz	1977	95	464	605
91	Pnei Hever	1982	98	522	548
92	Carmel	1981	182	347	605
93	Adora	1984	182	372	421
94	Qalya	1968	271	771	386
95	Ma'ale Amos	1981	89	310	390
96	Gittit	1973			430
97	Mevo Dotan	1978	96	768	386
98	Telem	1982	95	451	362
99	Sansana	1999	74	188	377
100	Negohot	1999	53	227	289
101	Yitav	1970	117	322	321
102	Migdalim	1983	66	136	305
103	Petza'el	1975	319	897	257
104	Tomer	1978	218	366	262
105	Vered Yeriho	1980			252
106	Gilad Farm	2002			
107	Hemdat	1980	75	202	230
108	Hermesh	1982	96	445	223
109	Rehan	1977	86	298	224
110	Almog	1977	107	397	239
111	Maskiyyot	1983	45	413	253
112	Beka'ot	1972	115	344	187
113	Netiv Hagedud	1976	234	1425	190
114	Mizpe Shalem	1971	72	108	174
115	Gilgal	1970	181	727	178
116	Rotem	1983	44	55	196
117	Ro'i	1976	106	164	165
118	Beit Ha'arava	1980	75	163	183
119	Yafit	1980	173	297	139
120	Massu'a	1970	162	692	162
121	Mechora	1973	103	171	142
122	Argaman	1968	109	353	131
123	Avenat	1983	43	89	193

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124	Hamra	1971	123	261	124
125	Naama	1982	119	280	116
126	Niran	1977	107	397	91

Source: The names of the settlements date of establishment, and number of settlers were taken from B'‘t Selem. The initial area and area in 2016 were taken from Wafa organization.

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